CRWR Online Report 06-13

Water Quality Data Model in GIS for the Rio Bravo/Grande Basin

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November 2006

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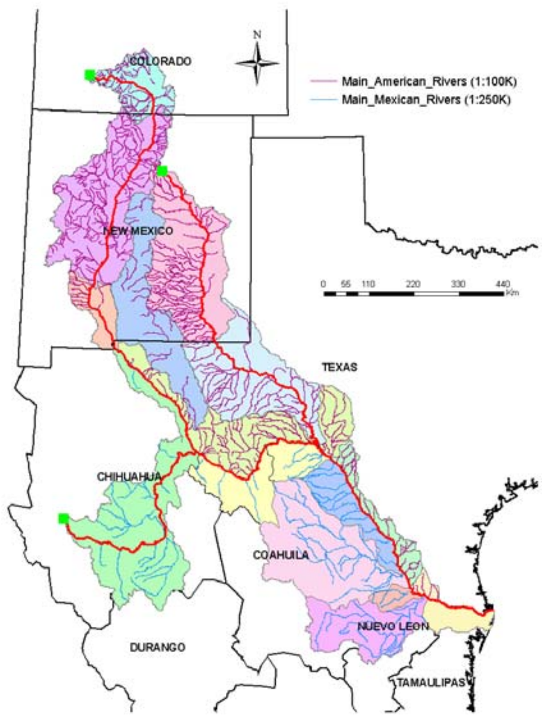
FINAL REPORT
Prepared by
The University of Texas at Austin
November, 2006



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Abstract

In previous research, the Center for Research in Water Resources (CRWR) of The University of Texas at Austin, and the National Water Commission (CNA) of Mexico cooperated to develop the Rio Grande/Bravo a database in which most of the data are referenced geographically (i.e., a geodatabase). The geodatabase consists of a Geographic Information System (GIS) and a relational database containing hydrologic, hydraulic and related data for the basin. ArcHydro was used as the basis of the geodatabase since it allows the river basin to be represented in a realistic network of upstream to downstream connections. The ArcHydro data model defines attributes, relationships, and connectivity between hydrologic features in a GIS database. Now that the Rio Grande/Bravo geodatabase has been created, it is available for use in various water management agencies within the U.S. and Mexico, and these agencies have shown great interest in its use. In this project, CRWR and CNA have cooperated to build on the results of the previous project to accomplish three tasks: (1) add water quality data to the Rio Grande/Bravo geodatabase; (2) add water related infrastructure data to the Rio Grande/Bravo geodatabase; and (3) determine the main river segments in this basin to be used in the water quality modeling. This project assists in developing bi-national cooperation between Mexico and the United States concerning water in the Rio Grande/Bravo basin, providing accurate and reliable data necessary for analysis and resolution of water resources issues.

Contents

1 Statement of problem

The Rio Grande/Rio Bravo River is a transboundary water source shared by the United States and Mexico. The river is the lifeblood for much of the economic activity in the Rio Grande/Bravo valley on both sides of the border. A continually increasing population, serious problems related to lack of sanitation and clean water, as well as regular high investments in infrastructures which are not achieving their objectives, are likely to force governments at various levels to search for alternative approaches, other than relying only on engineering solutions through supply management alone. The institutions concerned are aware that successful water resources management requires a long term planning process from technical, economic, political, social, and environmental viewpoints. Recently, the basin's highly developed water resources and decade-long drought conditions have created tensions over water sharing in the basin. Areas of conflict and several possible negotiated remedies are being identified, but access to reliable data for analysis of alternative solutions to these problems is lacking. For this reason the development of watershed-scale databases including both water quantity and water quality information for the Rio Grande/Bravo basin is of critical importance. Minute 308 of the International Boundary and Waters Commission (IBWC), June 28, 2002, states that it is very important to support projects that increase data exchange related to the management of hydrological information systems. These systems should include information from both sides of the basin in a timely manner to enable the IBWC to adopt principles and understandings under which both Governments provide the highest priority to fulfilling their respective obligations under the 1944 Water Treaty.

This project helps to solve the fundamental problem of making accurate data available for decision makers in the basin. These data are being provided in the industry-standard ArcHydro geographic information system (GIS) which provides ready access to data for hydrologic and policy analysis using a wide variety of hydrologic, water quality, economic, and environmental models. ArcHydro makes it possible to store information about a river basin in a way that resembles the physical geography of the real basin, so that you can analyze effects from upstream or on downstream in a connected manner.

2 Objective

The main goal of this project is the development of a Water Quality Data Model (WQDM) for the whole Rio Grande/Bravo basin, based on a framework developed in Visio 2000 and exported as a schema into an access file. This data model is implemented following criteria and parameters from the International Boundary Water Commission (IBWC), Texas Commission on Environmental Quality (TCEQ), United States Geological Survey (USGS), Environmental Protection Agency (EPA), and Mexican National Water Commission (CNA). This georeferenced database includes spatial and temporal information related with water quality, as well as water related infrastructure data to the Rio Grande/Bravo, being implemented in a Geographic Information System (ArcGIS) following the ArcHydro data model structure developed at the Center for Research in Water Resources of the University of Texas at Austin (CRWR-UT). This relational database is related to the Water Quantity Data Model for the Rio Grande/Bravo basin already developed in a previous project by the CRWR and CNA.

3 Introduction and background

Box 1. Dividing the Rio Grande/Bravo Waters

Allocated to Mexico:

a) The flow of the San Juan and Alamo rivers, including the return flows from irrigated lands;
b) One-half of the runoff downstream of Falcon dam, whenever this volume is not allocated to one of the two countries;
c) Two-thirds of the flow of the Conchos, San Diego, San Rodrigo, Escondido, Salado and Las Vacas Rivers; and
d) One-half of all other unallocated flows to the main river.

Allocated to the United States:

a) The flow into the Rio Grande/Bravo from the Pecos, and Devils Rivers, Goodenough Spring, and Alamito, Terlingue, San Felipe and Pinto Streams;
b) One-half of the flow in the Rio Grande/Bravo below the lowest major international storage dam, if this volume is not allocated to one of the two countries;
c) One-third of the flow into the Rio Grande/Bravo from the Conchos, San Diego, San Rodrigo, Escondido, Salado Rivers and Las Vacas Stream and not less than 431,721,000 cubic meters

Water issues in the basin. The Rio Grande/Rio Bravo drainage basin includes parts of three U.S. states (Colorado, New Mexico and Texas) and five states in Mexico (Chihuahua, Durango, Coahuila, Nuevo Leon, and Tamaulipas). The river carries little water compared to other rivers of its length. Typical of rivers that pass through arid regions, it tends to shrink in size as it flows downstream. Most precipitation in the basin falls at either end of the river, as snow near its headwaters or as rain near its mouth. Mexico irrigates about 1.1 million acres in the basin, while the United States irrigates about 993,000 acres. Only 98,000 acres of irrigated land lie upstream from Texas. The Conchos, Salado, San Rodrigo, Alamo, and San Juan Rivers are the primary tributaries in Mexico. The Pecos and Devil Rivers are the principal tributaries to the river in Texas.

Historical treaties about the water distribution in the Rio Grande/Rio Bravo basin. The problem of water distribution in the Rio Grande/Rio Bravo basin arose in 1899, when due to diversions on the American side; water did not arrive in Ciudad Juarez where it was needed for irrigation during a drought. In 1906, a Convention was signed for the joint U.S.-Mexican administration of the Rio Grande/Rio Bravo and dividing the waters above Ft. Quitman, Texas.

Following this, a Treaty was signed in 1944 dividing the waters below Ft. Quitman in a specific way between the two countries (See Box 1).

Current conditions in Mexico.

Mexico has high water availability, however; precipitation occurs over a few months and this is regionally concentrated. Additional difficulties are generated because most of the Mexican population and economic activity in the basin are located in areas with very low precipitation. For this reason it is important to improve the efficiency of water administration and management in Mexico. This requires an assessment of water availability and management for municipal use, agriculture, industry and other uses, taking into account ecosystem preservation. The recently adopted water law of Mexico (April, 2004) requires a decentralization of water resources management authority to the basin level along with consideration of stakeholder opinion in formulating basin management plans.

Current conditions in the United States.

In some areas of Texas, especially the Rio Grande basin, essential water needs may be threatened during severe drought. Moreover, new water issues including the need for environmental flows to maintain in-stream habitat as well as to protect the ecological health of bays and estuaries have emerged in Texas. Given the size and complexity of the state's water demands, and the complex water management situation in the Rio Grande/Bravo basin, Texas has been developing new management tools (water availability models) to identify, assess, and resolve its water resource issues. The Texas Legislature in 1997 passed Senate Bill 1, a comprehensive water package that addresses a wide range of issues including the need to expand statewide water availability modeling capabilities in support of regulatory and planning activities.

3.1 Past Activities

In a previous project, the Center for Research in Water Resources (CRWR) at the University of Texas at Austin, and the National Water Commission (CNA) of Mexico cooperated to develop a database of hydrologic information for the Rio Grande/Bravo basin that is geographically referenced (i.e., a geodatabase). The geodatabase consists of a geographic information system (GIS) and a relational database containing hydrologic, hydraulic and related data for the basin. ArcHydro was used as the basis of the geodatabase since it allows the river basin to be represented in a realistic network of upstream to downstream connections. The ArcHydro data model defines attributes, relationships, and connectivity between hydrologic features in a GIS database. The data collected from the original sources are included in Table 1, as well as some of the data characteristics. ArcHydro has recently been developed at CRWR to facilitate access to hydrologic information by models (Maidment, 2002). The geodatabase has been made available to Mexican and U.S. federal, state, and local organizations, and training has been provided in Spanish and English to facilitate its use. The geodatabase is assisting in enhancing bi-national cooperation between Mexico and the United States concerning water in the basin, providing accurate and reliable data necessary for analysis and resolution of water resources issues.

Table 1 Data Sources for Rio Grande/Bravo Water Quantity Geodatabase

Data	Source
Political boundaries	US: Department of Transportation Mexico: INEGI (1:250K)
Basin Delineation	US: USGS-HUC (1:100K) Mexico: Cuencas and Sub-Cuencas from IMTA and UACJ (1:250K)
Hydrography (Stream network)	US: USGS (1:100K) Mexico: IMTA, CNA, INEGI, and UACJ (1:250 K)
Water Bodies and dam locations	US: USGS- HUC'S (1: 100K) Mexico: IMTA, CNA, and UACJ (1:250K)
Monitoring points	US: USGS and IBWC Mexico: IMTA, CNA and CILA
Monitoring points time series	US: USGS NWIS and IBWC Mexico: CNA, IMTA and CILA
Climatologic time series	US: USGS and PRISM Mexico: IMTA and CNA
Digital Elevation Model (DEM)	US: USGS (30 m cell size) Mexico: INEGI (Cell size: 104 m)
Control Points (water rights, return flow points, diversions, etc)	US: TCEQ Mexico: CNA

The Rio Grande/Bravo geodatabase represents the first major attempt to establish a more complete understanding of the basin as a whole, using both Mexican and the U.S. data.

Hydrological and other information were obtained from Mexican and U.S. agencies, including: political boundaries, river network, water bodies, gauging stations, Digital Elevation Models (DEMs), etc. Temporal climatic and hydrological data were imported from various U.S. and Mexican databases corresponding to monitoring points located in the Rio Grande/Bravo basin (figure 1).

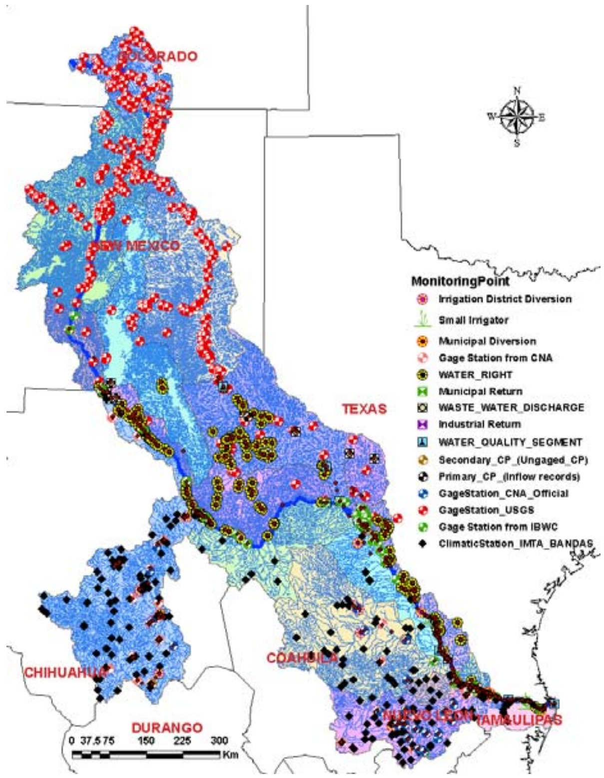

Figure 1 Water quantity geodatabase for the Rio Grande/Bravo basin

3.2 Brief introduction to the Rio Grande/Bravo basin

The Rio Grande/Bravo is a transboundary water source shared by the United States and Mexico. This river originates in the San Juan Mountains of southern Colorado, flows 1,073 km from its headwaters through the state of New Mexico where it enters Texas about 12 km northwest of El Paso, and continues for 2,034 km to the Gulf of Mexico. Figure 2 shows the political division and main tributaries of the Rio Grande/Bravo basin with Hydrologic Unit Code (HUC) areas on the U.S. side and Cuencas and sub-Cuencas on the Mexican side. The Rio Grande is the fifth longest river in North America (3,107 km), and among the 20 longest rivers in the world. The river carries little water compared to other rivers of its length and it tends to shrink in size as it flows downstream, typical of rivers passing through arid regions. Most precipitation in the basin falls at either end of the river, as snow near its headwaters or as rain near its mouth, especially on the Mexican side.

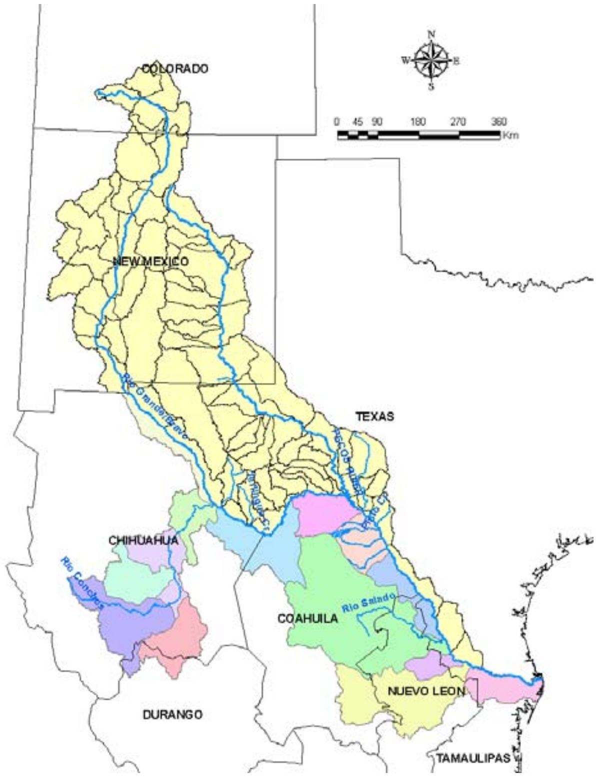

Figure 2 Political Division of the Rio Grande/Bravo basin

The river collects rain, snowmelt and spring water from an area about 557,722 km^2 (including closed basins). The basin includes 242,994 km^2 in three states on the U.S. side (Colorado, New Mexico, and Texas), and 225,380 km^2 in five states on the Mexican side (Chihuahua, Coahuila, Durango, Nuevo Leon, and Tamaulipas).

The basin is comprised of two sub-basins: the Upper Rio Grande basin (above Ft. Quitman, Texas) includes Colorado, New Mexico, and part of Texas, and the Lower Rio Grande Basin (below Ft. Quitman) includes parts of Chihuahua, Durango, Coahuila, Nuevo Leon, Tamaulipas, and Texas states. The study area for this work is the whole basin, encompassing the drainage of all major tributaries including the Rio Conchos and Pecos River tributaries. About

478,400 ha are irrigated on the Mexican side of this basin (CNA, 2003), while the United States irrigates about 402,000 ha (The Alliance for the Rio Grande Heritage et al, 2000). The Conchos, San Pedro, San Rodrigo, Alamos, and San Juan Rivers are the primary tributaries in Mexico, and the Pecos and Devil Rivers are the principal tributaries to the river in Texas (Figure 2).

The Rio Grande/Bravo basin is considered an arid to semi-arid region, dominated by agriculture and with a limited supply of surface water. The diversions of the Middle Rio Grande Conservancy District in the Albuquerque area and also the diversions of the Elephant Butte Irrigation District near Las Cruces, New Mexico are very important large diversions with major impacts on surface hydrology in the Upper Rio Grande/Bravo basin. Most of the remaining flow of the Upper Rio Grande/Bravo is diverted for irrigation and municipal uses at the American Canal in Texas and the Acequia-Madre Canal in Mexico when it reaches El Paso region. Downstream of El Paso, most of the flow consists of treated municipal wastewater from El Paso, rainfall runoff and irrigation return flow. Flow increases again at Presidio/Ojinaga where inflow from the Rio Conchos enters the Rio Grande/Rio Bravo (TWDB, 2001).

Average rainfall in the basin ranges from 200 – 900 millimeters with the highest values in the upper basin of the Rio Conchos (Eaton and Hurlbutt, 1992). The Rio Conchos enters to the Rio Grande/Bravo near Presidio, Texas, just upstream of Big Bend National Park and Ojinaga, Mexico; in a region of mountains and canyons. The basin ranges from arid and suitable for crops, to semi-arid and hospitable to some crops only. Along the entire river, water lost through evaporation exceeds water gained from precipitation. The lower Rio Grande valley serves as temporary or permanent home for hundreds of bird species, and the river contributes vital fresh water to its gulf estuary (Tate, 2002). At this time, Mexico is in the process of developing plans to improve water management in the Rio Bravo basin, given the existing and potential infrastructure and methods of application and distribution of water.

Drought is a persistent problem in the Rio Grande/Bravo basin. However, a recent drought event from 1992 to 2003 lasted longer than was ever anticipated in the negotiations of the 1944 treaty between the U.S. and Mexico. This drought lasted more than 10 years and created numerous difficulties in the lower Rio Grande basin below Ft. Quitman, Texas. As a result of the drought, Mexico was unable to deliver the quantities of water required under the 1944 Treaty and accumulated a “water debt” at the end of two consecutive five-year treaty accounting cycles. Meeting that treaty obligation became extremely difficult for Mexico during the recent drought. This drought drove the IBWC/CILA to develop and implement IBWC/CILA Minutes No. 307 and 308 which called for joint data sharing, joint drought management, and the convening of a binational mechanism towards sustainable management of the Rio Grande/Bravo basin (IBWC, 2002).

4 Methodology

4.1 Data collection

Data regarding to the water quality control points and its corresponding historical information on the American side was collected from the International Boundary Water Commission. This info is classified in two parts; one of them is included in the ‘IBWC Water Bulletins (http://www.ibwc.state.gov/EMD/Water_Bulletins/Water_Bulletins.htm)” and the other one is part of the “Texas Clean River Project (http://www.ibwc.state.gov/CRP/monstats.htm)”. The Clean River Project (CRP) is being achieved among several agencies such as IBWC and TCEQ. All original data is included in excel spreadsheets and cover info since 1995 – 2005 in the most cases. The rivers are classified by the TCEQ with a specific segment ID, which will be preserved in the Water Quality Data Model (WQDM). These river segments are reported as a shapefile in the TCEQ website (http://www.tnrcc.state.tx.us/gis/ourmaps.html). The waterbodies included in the WQDM will be gathered from the TCEQ for the American side, preserving its classification criteria. The river segments, water quality control points and waterbodies information on the Mexican side of the basin were collected from the CNA or SEMARNAT agencies. Table 2 describes the water quality information collected from the Mexican and American agencies for this project.

Table 2 Water quality data inventory in the Rio Grande/Bravo basin

Information Type	Original Format	Scale	Source	Comments
Wastewater discharges (Geographic position of 586 Monitoring Points on the Mexican side)	Excel, Shapefiles	N/A	Mexico: REPDA-CNA USA: EPA, IBWC, TCEQ	Information collected from the Border Affairs CNA on April 2005
Wastewater treatment plants (Geographic position of 203 plants on the Mexican side)	Dbase, Excel and Shapefiles	N/A	Mexico: RAISON-CNA USA: EPA, IBWC, TCEQ	Information from the Raison data model developed by IMTA at 1998
Water Quality Stations on the Mexican side. Position of 7 points at the primary network (fixed points) and 3 at the secondary network (changing points) Water Quality Stations on the American side: Positions of more than 2 thousands water quality stations in the whole basin	Excel Shapefile	N/A	SNICA- CNA EPA, IBWC, TCEQ, TNRIS	Information received from Jesus Cabrera on Dec 2005. Location of these points is similar to the RAISON WQ stations.
Political boundaries	Shapefile	1:250K	US: Department of Transportation Mexico: INEGI	
Basin Delineation	Shapefile	USA: 1:100K Mexico: 1:250K	US: USGS-HUC Mexico: Cuencas and Sub-Cuencas from CNA	
Hydrography (Stream network)	Shapefiles	1:100K 1:250K	US: USGS Mexico: IMTA, CNA, INEGI, and UACJ	
Water Bodies and dam locations		1:100K	US: USGS-HUC'S	

		1:250K	Mexico: IMTA, CNA, and UACJ	
Monitoring points time series	Dbase and txt files	N/A	US: USGS and IBWC Mexico: IMTA, CNA and CILA	
Climatologic time series	Dbase and txt files	N/A	US: USGS and PRISM Mexico: IMTA and CNA	
Digital Elevation Model (DEM)	Raster	USA: 30 m cell size) Mexico: 30m Cell size	US: USGS Mexico: INEGI	
Control Points (water quality stations, waste water discharge, NADBank projects, hydraulic infrastructure, etc)	Excel, Shapefiles, Coverages	N/A	US: TCEQ Mexico: CNA and other Mexican agencies as necessary	
River segments	Shapefiles, coverages	1:100k 1:250K	US: USGS Mexico: CNA, INEGI.	US: They will be generated using the hydrological information from the CRWR - UT (1:100K). The RF1 from EPA will be used as reference. Mexico: They will be generated using the hydrological information from the CRWR-UT (1:250K)
Water Quality time series	Excel, txt files		US: EPA, IBWC, TCEQ, USGS, TNRIS, Mexico: CNA – SNICA data model and SEMARNAT. It is included in an	

			Excel spreadsheet	
Digital Orthophoto Quadrangles (DOQ)	TIF and Raster	1:100K 1:250K	US: USGS Mexico: INEGI	US: USGS, the Landsat scenes will be resampled to a 1 –arc-second (approximately 30 meter) sample interval. Three bands are selected from the eight spectral bands available for each frame. Mexico: INEGI
Continuous Water Quality Monitoring Stations and Data (List Real Time)			US: TCEQ	US: http://www.tceq.state.tx.us/compliance/monitoring/water/quality/data/wqm/swqm_realtime_alt.html#data
Roads		1:100 K 1:250K	US: USGS seamless format Mexico: INEGI	

4.2 Developing the schema of the Water Quality Data Model (WQDM)

A water quality framework is being created in Visio 2000 to have the Rio Grande Water Quality UML file. This framework follows the ArcHydro data Model philosophy, but some changes are being made to the attribute tables of the feature classes, in order to met criteria and parameters required by the TCEQ, EPA, USGS, IBWC, CILA, and CNA (Figure 3 & 4).

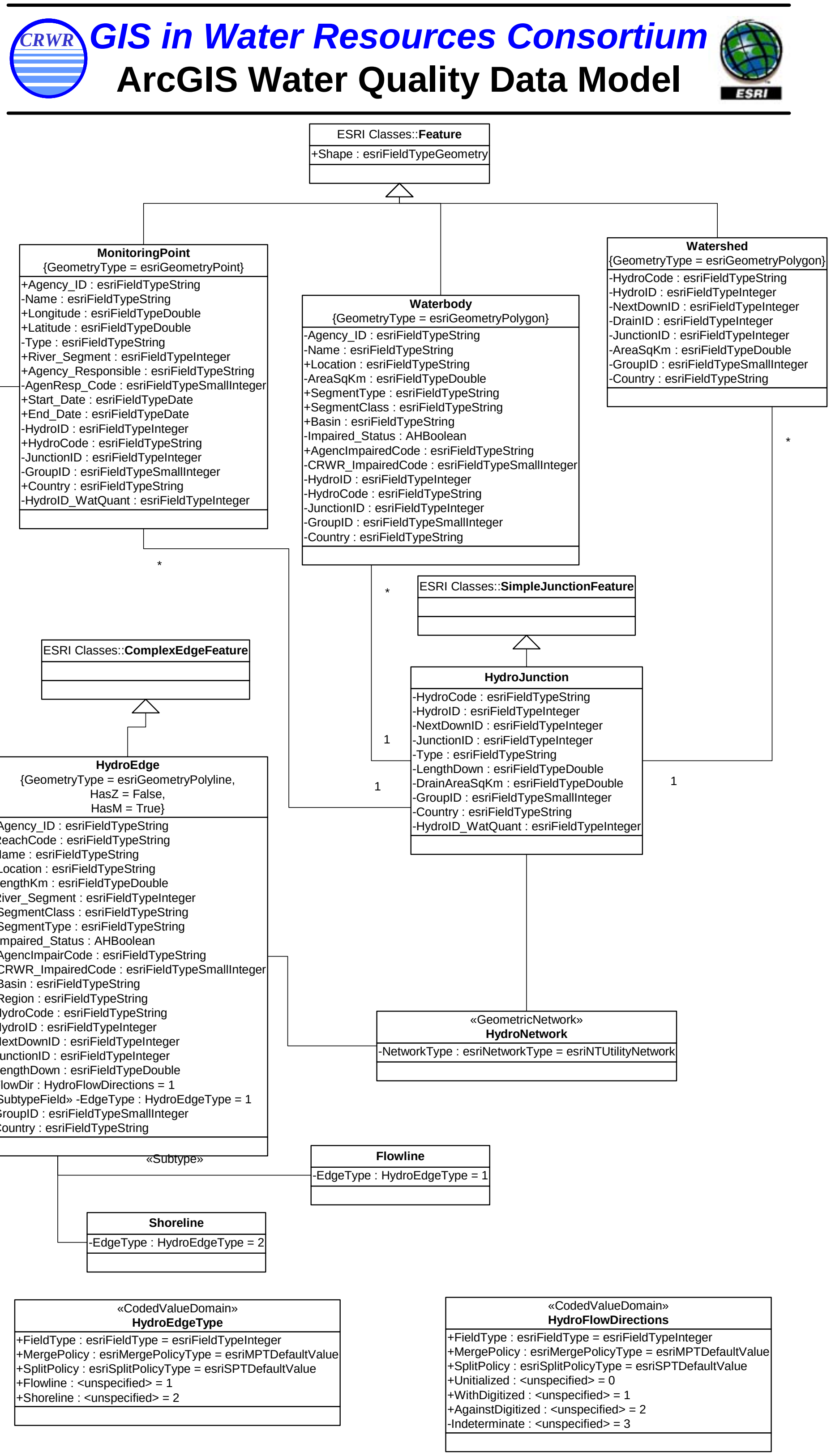

Figure 3 UML file for the WQDM

Time Series

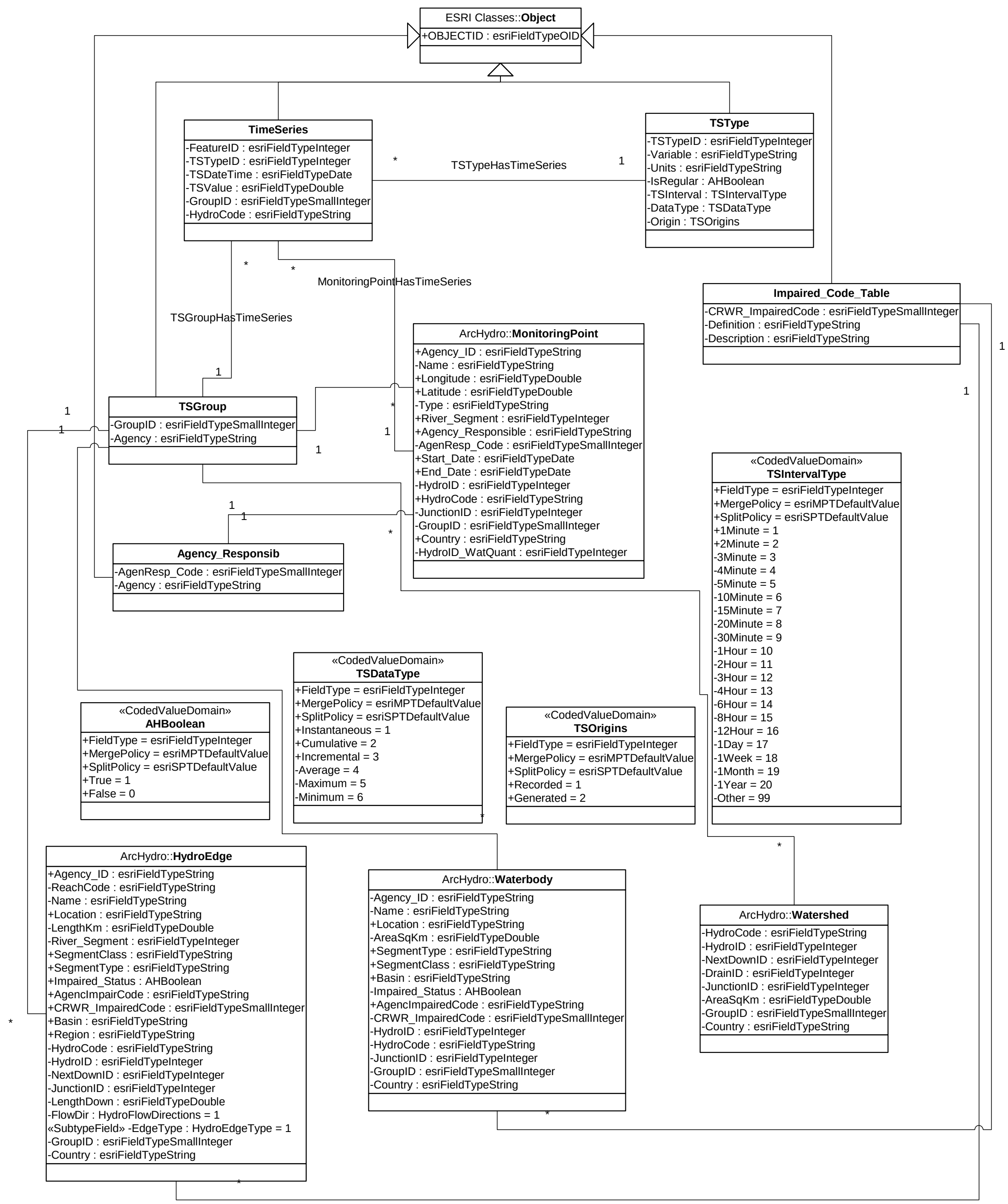

Figure 4 Time Series UML file for the WQDM

Once the Water Quality Data Model UML has been created, it must be exported as mdb file to create the schema, which is applied to an empty relational geodatabase using ArcCatalog (Figure 5).

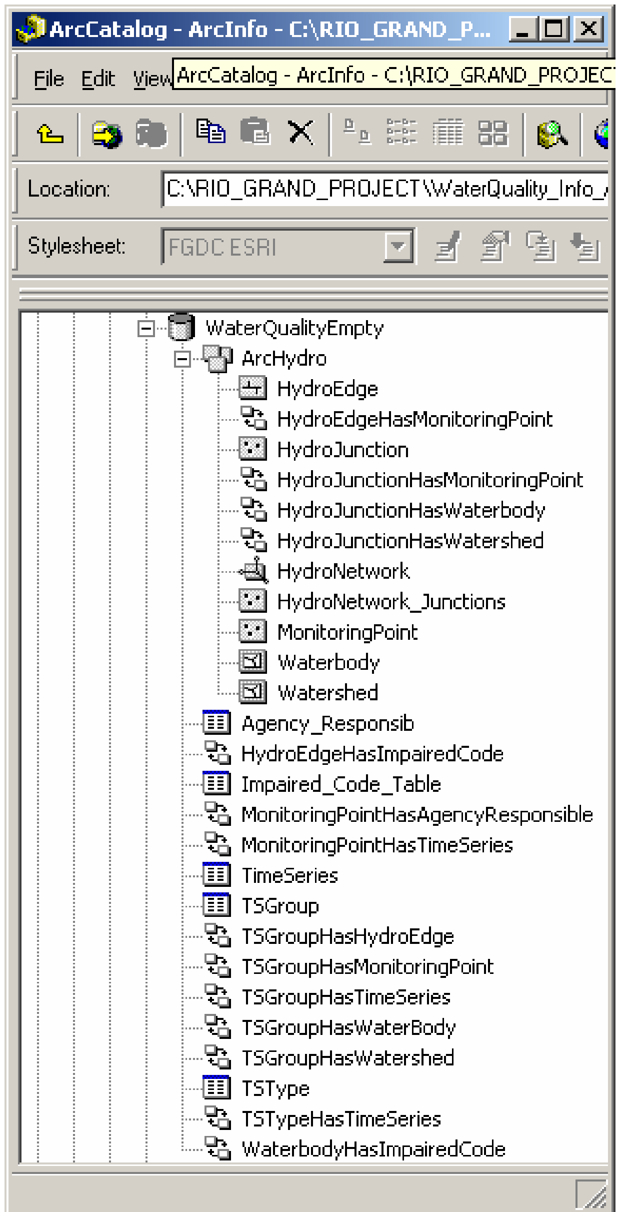

Figure 5 Water Quality Data Model Framework

4.3 Spatial reference information

Projected Coordinate System: NAD_1983_Albers

Projection: Albers

False_Easting: 1000000.00000000

False_Northing: 1000000.00000000

Central_Meridian: -103.00000000

Standard_Parallel_1: 27.41666667

Standard_Parallel_2: 34.91666667

Latitude_Of_Origin: 31.16666667

Linear Unit: Meter (1.000000)

Geographic Coordinate System:

GCS_North_American_1983

Datum: D_North_American_1983

Prime Meridian: 0

4.4 Developing the Geodatabase

The development of a water quality watershed-scale database in conjunction with a water quantity database is fundamental to analyzing water resource management problems in the Rio Grande/Bravo basin. Even though separate research efforts have been carried out on each side of the river, integral databases including water quantity and water quality information have not been created previously that includes data from both sides of the basin. As in many watersheds, knowledge and information available about the Rio Grande/Bravo basin is fragmented, disjointed, incomplete, and sometimes inaccurate. Integrated management of a river basin requires the development of models that are used for many purposes, e.g., to assess risks and possible mitigation of droughts and floods, manage water rights, assess water quality, and simply to understand the hydrology of the basin. For this purpose a database that includes water quality parameters is needed to complement the hydrologic data model developed in a previous project, and from which models can access the various data needed to describe the systems being modeled (figure 6). In other words, a database from which models read input data and to which they write output data. In order for this concept to work, however, it must have a standard design. The adapted ArcHydro data framework facilitates access to water quality information by models.

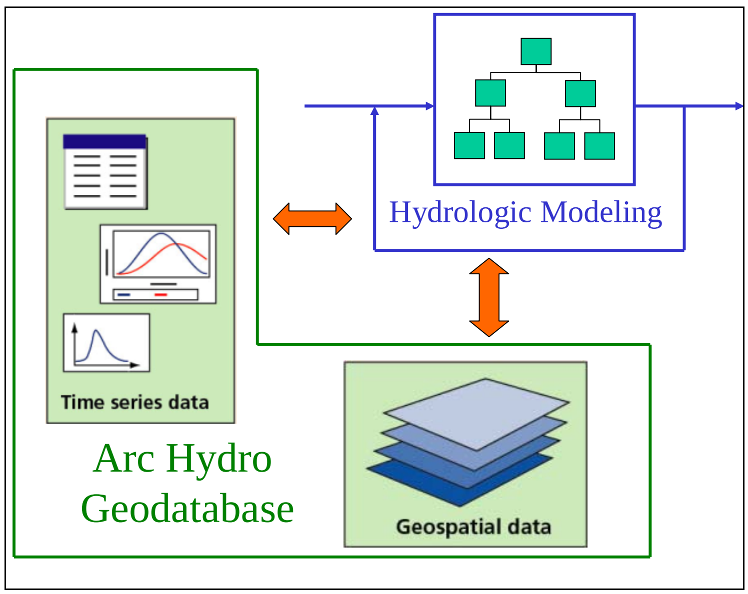

Figure 6 Hydrologic Information System (Maidment, 2002)

Creating an ArcHydro geospatial database that includes water quality information for the entire Rio Grande/Rio Bravo basin represents the first major attempt to establish a more complete understanding of the basin as a whole, using both Mexican and U.S. geospatial and temporal data for water resources. It is possible to obtain from the database information about water quality parameters, water quality stations, water uses, hydraulic infrastructure like waste water discharges, and drainage in the basin that are included as feature classes within the relational database (Figure 7). These data will permit models to simulate the contaminant transport and development scenarios and management plans in the future.

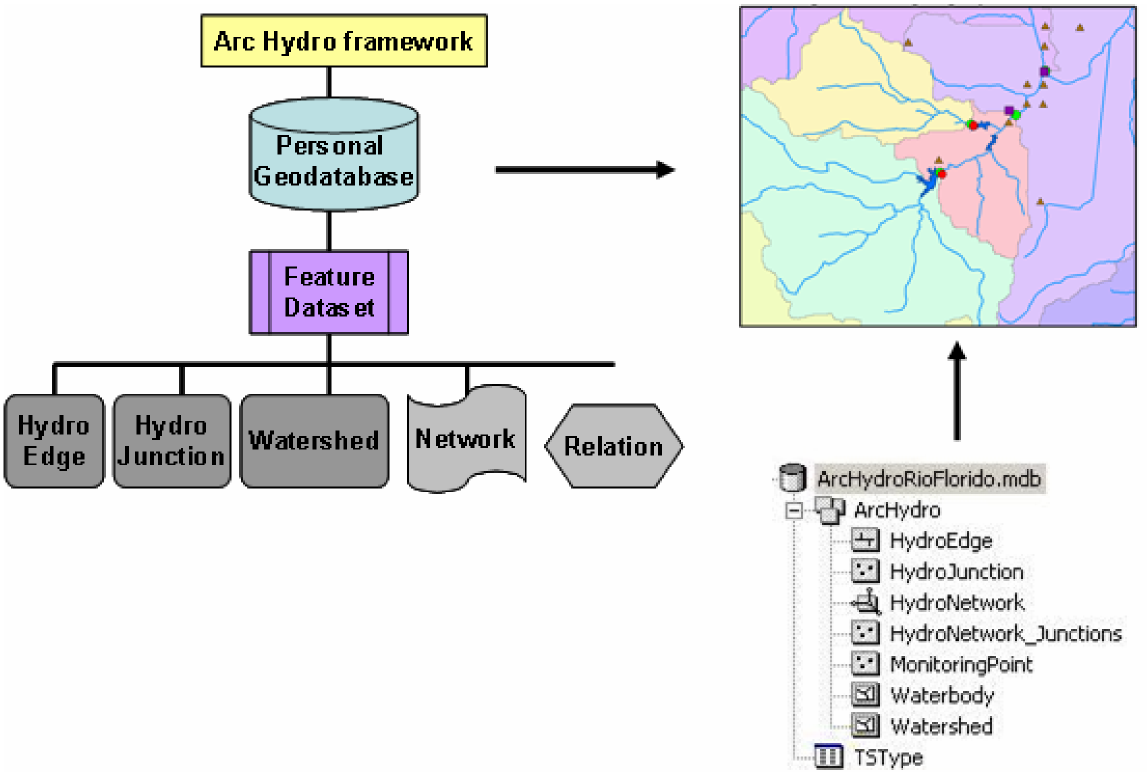

Figure 7 ArcHydro water quality data model for water resources

4.5 Clipping and Merging Data Sets

In constructing the Water Quality Data Model (WQDM) for the Rio Grande/Bravo basin, data distributed on a national or state level had to be clipped to remove information outside the study area; while data distributed at a county or Hydrologic Cataloging Unit level, had to be merged into a single and larger data set. Because the original DEM for Mexico existed for the whole country with a grid size of 104 m, it had to be clipped and resampled on a 30 m grid (to make it compatible with the resolution of the data on the U.S. side) based on the basin boundaries. With respect to the USGS DEM for the U.S. side, the original seamless tiles are projected using the GCS_1983 and a grid resolution of 28.3 m; so they had to be reprojected and resampled to match the projection and characteristics chosen for the project. The result of this step is shown in Figure 8.

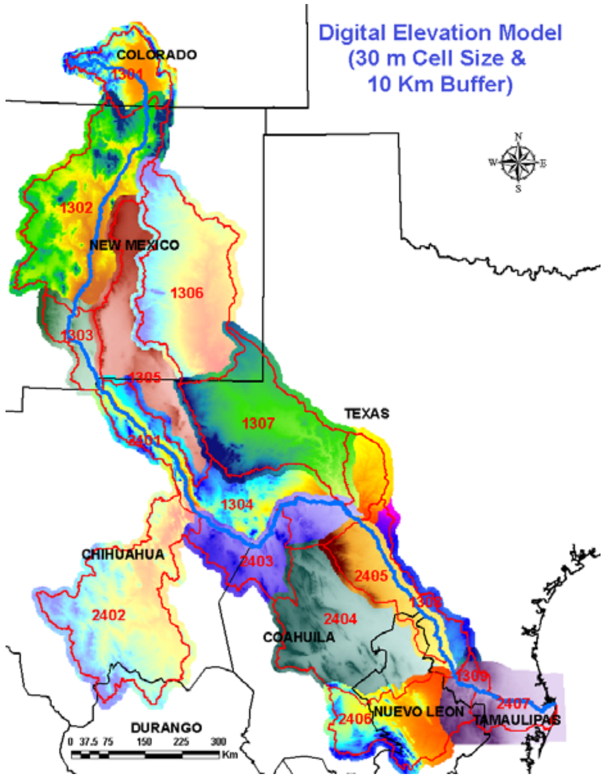

Figure 8 Clipped DEMs for the basin including a 10 Km buffer

4.6 Creating Feature Datasets

This step consisted of entering and processing the available information into the Water Quality Data Model (WQDM) for the Rio Grande/Bravo. Several feature datasets (essentially, sets of data with specific characteristics in the geodatabase) were created that include feature classes (layers of data within the feature datasets) related to each type of information. Figure 9 shows the geodatabase structure including the Feature datasets.

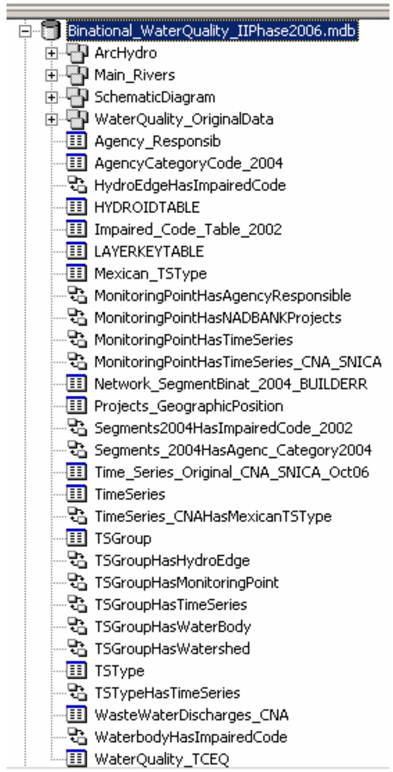

Figure 9 Feature dataset included in the Water Quality Data Model (WQDM)

4.6.1 ArcHydro Feature dataset

This feature dataset includes the full water quality data model. It includes the river network (HydroEdge feature class); control points as the water quality stations, waste water discharge, NADBank project locations, etc included in the MonitoringPoint feature class; lakes and dams included in the WaterBody feature class; the SnapControl point feature class that includes the control points snapped on the river network; the HydroJunction feature class that are virtual points participating in the geometric network and representing the original control points; and the watershed feature class that includes watersheds delineated for every HydroJunction for the whole basin.

4.6.2 Main Rivers Feature Dataset

This feature dataset includes all the main rivers identified in the whole Rio Grande/Bravo basin, following the Reach File 1 (RF1) from the Environmental Protection Agency on the American side and the Mexican National Water Commission criteria on the Mexican side.

4.6.3 Schematic Diagram Feature Dataset

This feature dataset includes a schematic network diagram for the whole basin. This schematic network is a simplification of the HydroNetwork that consists of separate point and line feature classes called Schematic-Node and Schematic-Link, respectively. The schematic network is an abstract representation of the elements to which hydrologic or water management models can be applied, and it provides a simplified view of the connectivity of the river network and the control points. This kind of network is useful as a visual check to make sure that the hydrologic elements needed for a model are correctly linked in the landscape (Maidment, 2002).

4.6.4 Water Quality Original Data Feature Dataset

This feature dataset includes all the original information used to define the final version of the ArcHydro data model. Users can get more detail information related with the waste water discharges, original water quality stations, original information from the NadBank projects, original river segments from the TCEQ, and more.

4.7 Processing

4.7.1 Creating HydroEdges

This feature class depicts the river network for the whole basin, using a 1:100,000 scale on the American side and 1:250,000 on the Mexican side (figure 10). Fragmented segments were found in the original river segments from the TCEQ, IBWC and INEGI, and then they were merged in ArcGIS so that each displayed segment was represented by only one record in the table.

This HydroEdge features class is used to derive the TCEQ Stream Segments for the State of Texas as listed in Title 30, Chapter 307 of the Texas Administrative Code (TAC), also known as the Surface Water Quality Standards on the US side, and the official CNA or SEMARNAT Stream Segments for the Mexican side of the Rio Grande/Bravo basin. These are streams and waterbodies that have been individually defined by the TCEQ and the other participating agencies and assigned unique identification numbers. **These river segments are included in the feature class called "Binational River Segments 2004," within the ArcHydro feature dataset.** Intended to have relatively homogeneous chemical, physical, and hydrological characteristics, a segment provides a basic unit for assigning site-specific standards and for applying water quality management programs of the agency. Both "classified" and "unclassified" segments have been included in this feature class. Classified segments, also referred to as designated segments, refer to water bodies that are protected by site- specific criteria. The classified segments are listed and described in Appendix A and C of Chapter 307.10 of the TAC. The site-specific uses and criteria are described in Appendix A. Classified waters include most rivers and their major tributaries, major reservoirs, and estuaries. Unclassified waters are those smaller water bodies that do not have site-specific water quality standards assigned to them, but instead are protected by general standards that apply to all surface waters in the state. This feature class also identifies which segments and water bodies have been listed as impaired or threatened in the final draft of the Texas 2000 Clean Water Act Section 303(d) List (effective August 31, 2000), as well as the river segments classification in the draft of the Texas 2004 Clean Water Act Section 303 (d) List (May 13, 2005) for the U.S. side of the Rio Grande/Bravo basin. An impaired segment is a water body which does not meet the standards set for its use, or is expected not to meet its use in the near future. The impaired code table associated with this feature class contains fields which indicate which segments are impaired and which pollutants are responsible for the failure of those segments to meet water quality standards.

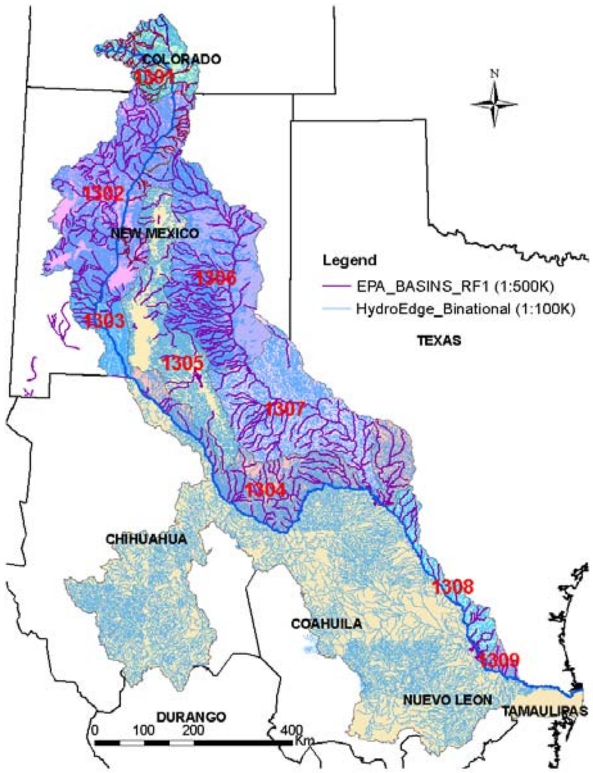

Figure 10 River network and the 2004 river segments classification

4.7.2 Creating Monitoring Points

This feature class shows all surface water quality monitoring being conducted by the TCEQ or under TCEQ contract for Fiscal Year 2005 on the Texas side, all water surface water quality monitoring identified by the CNA on the Mexican side, the NADBank project locations, and more (Figure 11). Other type of water quality points such as treatment plants location, waste water discharges, and hazardous points are included in this feature class within the WQDM. The water quality stations on the US side of the Rio Grande/Bravo basin was downloaded from the IBWC website (http://www.ibwc.state.gov/CRP/monstats.htm), where users can find the monitoring point locations considered in the IBWC-Clean River Project. To support coordinated monitoring, the TCEQ has developed guidance for site selection and for sampling requirements for routine, special study, and targeted monitoring. In this website http://www.tnrcc.state.tx.us/water/quality/data/wqm/coop_monitoring_2005.html, TCEQ provides more documents as support for the statewide coordinated monitoring effort on the Texas State.

The water quality stations on the Mexican side of the Rio Grande/Bravo basin were collected from the CNA technical sub direction, and some points published in the CNA website corresponding to the lower Rio San Juan sub basin. These points on Mexico are contained in the Sistema Nacional de Informacion de Calidad del Agua database (http://www.cna.gob.mx/eCNA/Espaniol/Programas/Subdirecciones/SGTCA/sitiossuiba.pdf).

All the monitoring points were merged getting a feature class called MonitoringPoint_Original and included in the Water_Quality_OriginalData feature dataset with 4814 points for the whole basin, but some of them lye outside of the border basin that would be checked out.

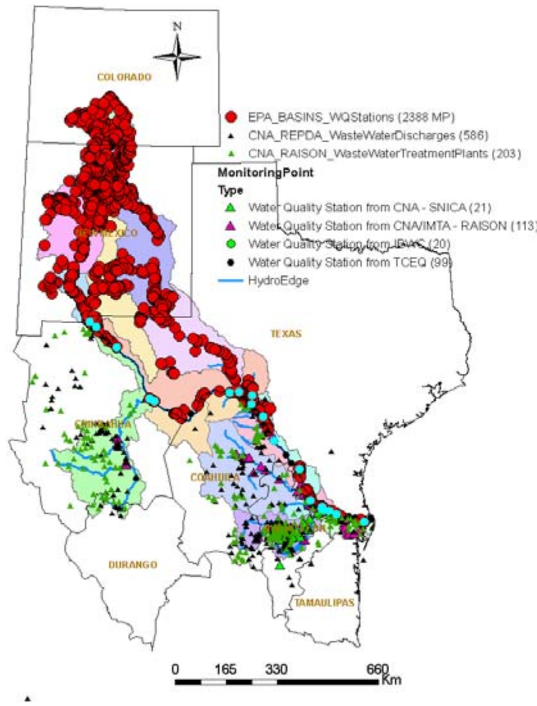

Figure 11 Total monitoring points included in the WQDM geodatabase

4.7.3 Feature Class: Waterbody

This feature class includes the water bodies, impaired or not, located on the Rio Grande/Bravo basin on both sides of the basin. Waterbodies are all the significant ponds, lakes, and bays in the water system. The American waterbodies are gathered from the USGS, EPA, and TCEQ, while the CNA and SEMARNAT provide the waterbodies information on the Mexican side (figure 12).

Figure 12 Binational waterbodies in the Rio Grande/Bravo basin

4.7.4 Feature Class: Watershed

This feature class includes information related to the drainage areas contributing flow from the land surface to the water system. The watershed information on the Mexican side is collected from the CNA and SEMARNAT, while this is being collected from EPA and TCEQ on the American side. The EPA manages water pollution using Total Maximum Daily Loads (TMDL) defined on watersheds draining to selected river segments or waterbodies, a different watershed layout than that used by the National Weather Service on the US. The WQDM is designed to allow any set of watersheds to be relationally connected to the hydro network, using the “area flows to a point on a line” concept to establish relationships between watersheds and HydroJunctions at their outlet location. Around 3000 watershed were determined for every HydroJunction (Figure 13).

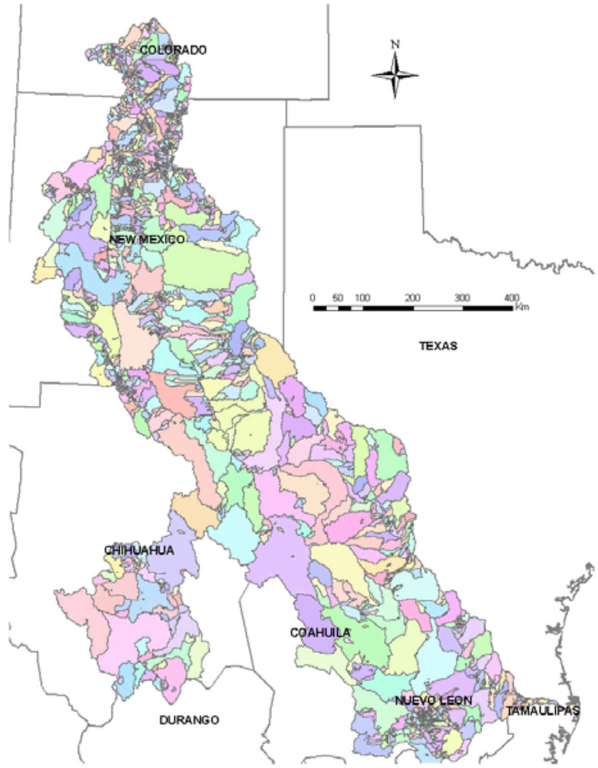

Figure 13 Watersheds determined for the Water Quality points

4.7.5 Feature Class: HydroJunction

This feature class includes a set of junctions located at the end of the river segments and at other strategic locations on the flow network. Since more than one monitoring point can exist at the same location, it is fundamental to have one point on the geometric network representing all of them. These points participating directly in the network are known as HydroJunctions in the ArcHydro jargon. Because the Monitoring Points preserve their original position, they are represented by the HydroJunction on the flow network. Since HydroJuctions are topologically linked to the river segments (HydroEdges) in the geometric network, the combination of this network and the other relationships means that the classes in the WQDM framework are connected into an integrated data structure. The HydroID is the key to establish the relationship between the HydroJunctions and the monitoring points. This unique value will be assigned to the

JunctionID value of the all monitoring points that are representing, so two or more monitoring points could have the same JunctionID

4.7.6 Creating the SnapControlPoint feature class

Because more than two monitoring points could be represented for just one HydroJunction in the geometric network, it is necessary to have one more feature class called SnapControlPoint. The SnapControlPoint is a point feature class that represents all monitoring points with all the features snapped to the right location on the network. The HydroCode is the unique identifier to establish the relationship between the SnapControlPoint and the Monitoring Point feature class. The main purpose of this feature class is to exchange information about water quality parameters between the HydroJunctions participating in the geometric network and the monitoring points, which maintain their original position.

4.7.7 Creating a geometric network

A geometric network is crated using the HydroJunction and HydroEdge feature classes. All points in the HydroJunction feature class were snapped the HydroEdge element. In order to avoid dividing the river segments into several parts, this geometric network is built as a complex edge.

4.7.8 Assigning Regional HydroIDs

The regional HydroID is the unique identifier used to establish the topology in the geometric network. The HydroID for the geographic elements would be assigned as described below:

The first digit (from left to right) indicates the hydrological region (blue box). Region 13 on the U.S. side was identified with the number 1, and number 2 identified region 24 on the Mexican side. The second 2 digits (yellow boxes) describe the Hydrologic SubRegion. The basin is divided into 9 sub regions on the U.S. side and 7 sub regions on the Mexican side. The next two digits (red boxes) correspond to the feature class; e.g. the value 01 was assigned for the MonitoringPoint feature class, while the value 02 was assigned for edges (River network). The monitoring points from the Mexican Water Quality Information National System (SNICA) where included in a feature class identified as 03; and so on. The last five digits (green boxes) describe the feature number, with a maximum of 99,999 values.

4.7.9 Water Quality Parameters

The ArcGIS format was applied to all historical records of the water quality parameters in order to include them in the geodatabase and relate them to the monitoring and control points. The ArcHydro Time Series format was changed, adding new tables containing information related to the agency from which data are derived and reason for why some river segments are considered impaired or not.

The inclusion time series data in the WQDM is not only to create a complete water quality data model for using the GIS environment, but also to build a relational database that would be accessible to many water quality models that operate separately of the GIS. The temporal information is captured and stored in a variety formats by each entity, so it is fundamental to have a standard design to manage large historical data sets. The original ArcHydro time series framework for the surface water is being modified to have a large container in GIS that allows storing many variables related to the water quality data that could include millions of records. Under this concept, user may acquire, store, or deliver an entire water quality data set, including time series data files from water quality stations, as well as the geographic element associated to it.

4.7.10 TSGroup table

This table describes the entity that manages and publishes some information. In this table users can identify from where the information comes, using a unique identifier for each agency. A relationship is established between the temporal information in the time series table and the Monitoring Point feature class using the FeatureID as the key.

4.7.11 TSType table

The TSType table contains an index of the types of time series data stored in the time series table. A relationship is established between the TSType table and the Time Series table using the TSTypeID as the key.

4.7.12 Impaired Code Table

This table is associated with the HydroEdge and WaterBody feature classes within the WQDM to indicate which river segments are impaired. The impaired code table contains fields to describe which pollutants are responsible for the failure of river segments to meet water quality standards.

4.7.13 Agency responsible table

This table describes which entity is in charge of the water quality stations. A relationship is established between the Agency responsible table and the Monitoring Point feature class using the AgenResp_Code attribute as the key.

4.7.14 Topology and relationships among the feature classes

A geometric network called HydroNetwork is created to establish the topology among the elements within the WQDM. This HydroNetwork becomes the backbone of the WQDM structure, created from the river segments (HydroEdges) and the water quality monitoring stations (HydroJunctions). The topological connection of its HydroEdges and HydroJunctions in the WQDM enables tracing of water movement upstream and downstream through streams and waterbodies. Relationships built from the HydroJunctions connect drainage areas, waterbodies and any point features such as water quality stations or wastewater treatment plants to the HydroNetwork. Each relationship has a multiplicity, and all the relationships implemented are one-to-many. One-to-many multiplicity means that one HydroJunction may be associated with one or more features in the related class. For example, two HydroEdges (river segments) may drain into a single HydroJunction on a river network

4.7.15 Regionalization process

The research presented in this project introduces a Raster-Network Regionalization Technique, which allows a large region to be divided into distinct subregions based on hydrological characteristics where raster analyses may be performed in a feasible manner. When working with huge basins like the Rio Grande/Bravo basin, the computer processor is not be able to handle the large raster datasets. This is handled by dividing the basin into sub-regions and processing the rasters individually for each sub-region. For this reason, the whole basin was divided into 9 hydrological subregions on the U.S. side, according to the USGS classification, and 7 hydrological subregions on the Mexican side, in order to apply the ArcHydro process subregion by subregion (Figure 14).

A summation of raster values over watersheds can be easily accomplished using the watersheds as distinct zones which define the area of analysis for the zonal statistics tool in ArcGIS. Once attribute values have been determined for watersheds, these values can be transferred to outlet junctions, and then consolidated throughout the stream network in the vector domain. The watersheds become the basic processing unit with basin-wide coverage, while the raster coverage can be reduced to each individual watershed's extent. Thus, watersheds effectively replace grid cells as the "units" of analysis.

The technique was successfully applied to the Rio Grande/Bravo basin. The results from the raster analysis of each subregion were merged on the vector side to determine the total drainage area flowing toward control points.

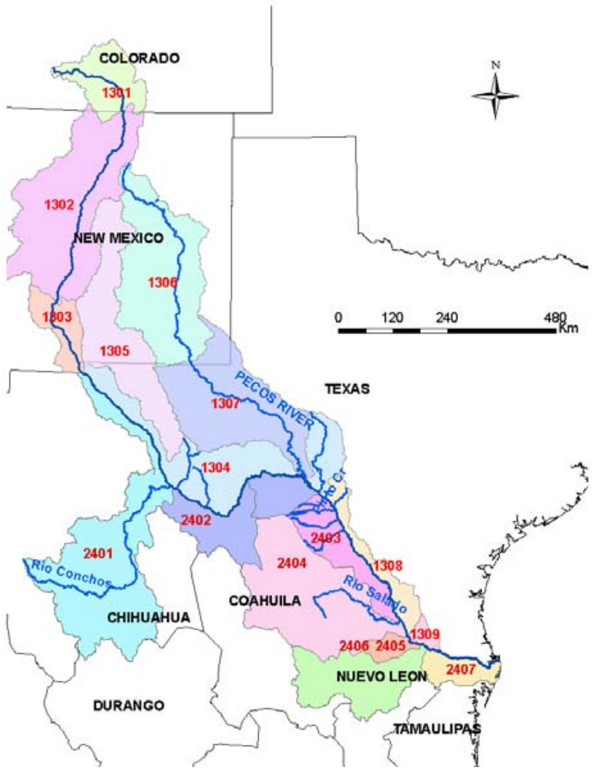

Figure 14 Hydrological sub regions of the Rio Grande/Bravo basin

A schematic network diagram for the whole basin is shown in Figure 15. This schematic network is a simplification of the HydroNetwork that consists of separate point and line feature classes called Schematic-Node and Schematic-Link, respectively. The schematic network is an abstract representation of the elements to which hydrologic or water management models can be applied, and it provides a simplified view of the connectivity of the river network and the control points. This kind of network is useful as a visual check to make sure that the hydrologic elements needed for a model are correctly linked in the landscape (Maidment, 2002)

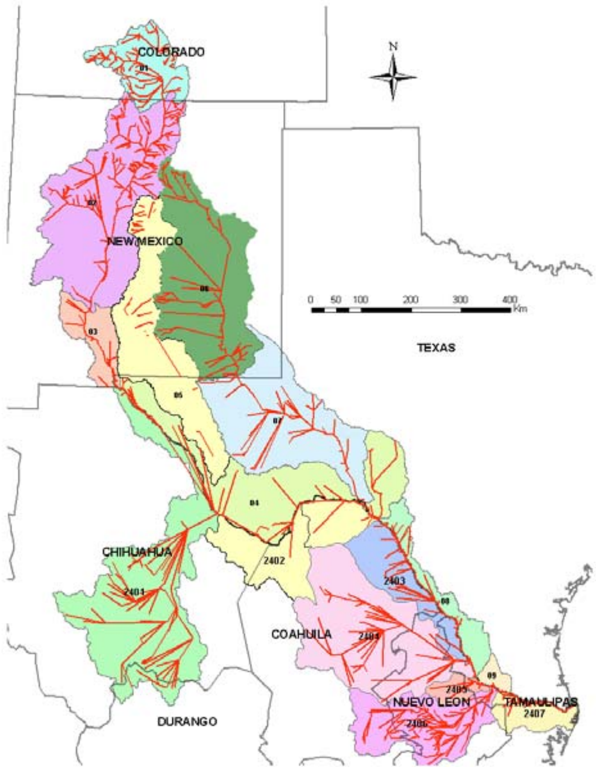

Figure 15 Binational Schematic Diagram

4.7.16 DISCREPANCY OF THE HYDROLOGIC DATA

There are some discrepancies in the information from the stream network RF1 used by the EPA, and the river network reported by the USGS (figure 16). For example, the Costilla Creek river, which is located between Colorado and New Mexico, and lies in the subregion 1302 according to the NHD classification, is an important tributary to the Rio Grande according to the USGS, but it is flowing to nowhere according to the RF1 system (1:500K).

A comparison for the river system is shown in figure 17, considering river versions from RF1, NHD (100K scale), and the drainage line produced from the Digital Elevation Model (30 m grid resolution).

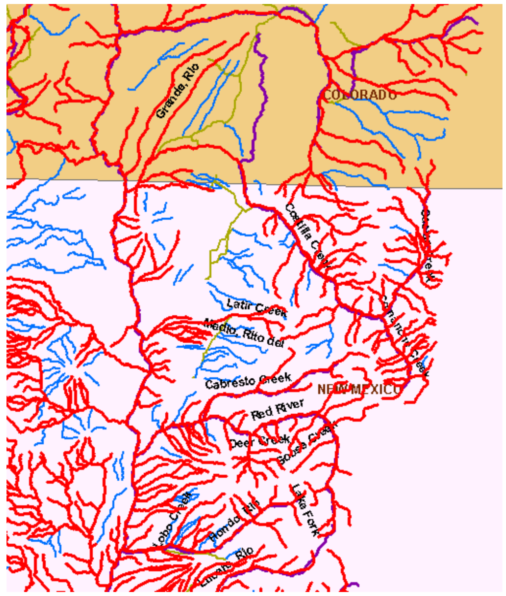

Figure 16 Comparison between RF1 and NHD river network

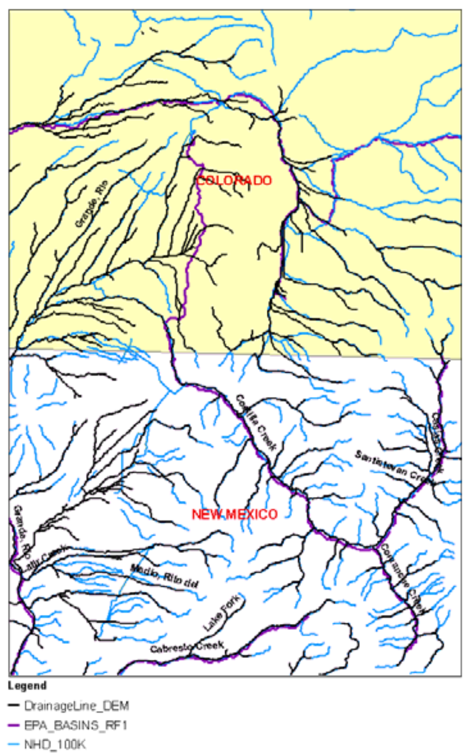

Figure 17 River network comparisons among NHD, RF1, and DEM versions

There are some inconsistencies in the hydrography of the upper basin. Figure 18 shows the comparison of the river network from RF1 and the NHD, after the last one was edited.

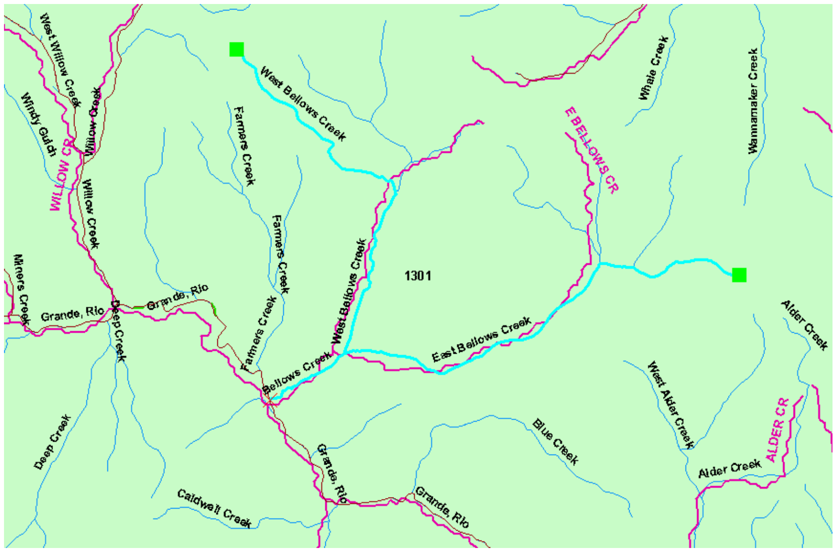

Figure 18 Comparison between the RF1 and fixed NHD stream network

4.8 Entity and attribute information

4.8.1 Attributes of the HydroEdge feature class

Attribute: HydroID. This is the unique 10 digit identification number assigned by the CRWR.

a). Attribute: HydroCode. This is the public identification number assigned by the TCEQ, USGS, EPA, IBWC, or CNA.

b). Attribute: ReachCode. This field is added to store the ReachFile from the EPA

c). Attribute: Name. The name of the classified or unclassified segment as it appears in the Texas Surface Water Quality Standards on the US side, and as it appears in the National Water Commission (CNA) or the Natural Resources and Environmental Secretary (SEMARNAT) classification on the Mexican side.

d). Attribute: LengthKm. This field indicates the river segment length in Km

e). Attribute: LengthDown. This field indicates the distance of the river segment to the outlet of the Rio Grande/Bravo basin, usually calculated in kilometers based on the HydroEdge attribute LengthKm.

f). Attribute: FlowDir. This field indicates flow direction of each river segment

g). Attribute: Agency_ID. This is a unique digit identification number as it appears in the TCEQ, EPA, IBWC, CILA, CNA, SEMARNAT, etc., databases for every river segment. This ID is usually the same as the HydroCode attribute

h). Attribute: SegmentClass. Classified: River Segments or water bodies that are protected by site-specific criteria as outlined in the TCEQ Surface Water Quality Standards. Unclassified: Smaller water bodies that do not have site-specific water quality standards assigned to them, but instead are protected by general standards that apply to all surface water in the state.

i). Attribute: SegmentType. Freshwater Stream: Inland waters which exhibit no measurable elevation changes due to normal tides. Tidal Stream: Descriptive of coastal waters which are subject to the ebb and flow of tides. For purposes of standards applicability, tidal waters are considered to be saltwater. Classified tidal waters include all bays and estuaries with a segment number that begins with 1323xx for the Texas side, all streams with the word tidal in the segment name, and the Gulf of Mexico. Reservoir: Any natural or artificial holding area used to store, regulate or control water. Estuary: Regions of interaction between rivers and near shore ocean water, where tidal action and river flow create a mixing of fresh and salt water.

j). Attribute: Location. Verbal description indicating where the stream segment or water body begins and ends.

k). Attribute: Basin. This field describes the name of the basin. Rio Grande/Bravo basin is the official name within the WQDM

l). Attribute: Region. This field describes the region where the stream segment is located, according to the TCEQ classification on the Texas side and the CNA classification on the Mexican side

m). Attribute: Impaired_Status_2004. Single-character field indicating whether or not the water body was impaired in the 2004 Surface Water Quality Standards effective on September 1, 2004. GIS Maps are available with results about impairing for 2000, but not for year 2004 in the TCEQ website (http://www.tnrcc.state.tx.us/water/quality/data/wmt/data_by_basin.html). These results were updated for 2004 in the WQDM.

n). Attribute: AgencyCategoryCode_2004. An alphanumeric code from the agency indicating why the water body is listed as impaired. This attribute will be related with the impaired segments through the Agency_Category_2004 identifier.

o). Attribute: Agency_Category_2004. An alphanumeric variable related to the impaired code from the agency. There was established a relationship between this attribute and the Agency Category Code_2004 table to describe why the river segment or waterbody is considered as impaired.

A relationship will be established between a river segment and its corresponding water quality monitoring station (Identified as a Monitoring Point within the geodatabase). Another relationship will be established between the river segments (HydroEdge) and the HydroJunction feature class. The HydroJunction is a virtual point representing a monitoring point in the geometric network.

5 Results

5.1 River segments

The hydrography described as HydroEdges in the Rio Grande/Bravo basin geodatabase for the water quantity is being used to define these river segments within the WQDM according to the RF1 network from the EPA. A similar river segments schema is proposed on the Mexican side. Originally this hydrography has a scale of 1: 100,000 on USA, while 1:250,000 on Mexico (figure 19). Fragmented segments were merged in ArcInfo so that each displayed segment was represented by only one record in the table.

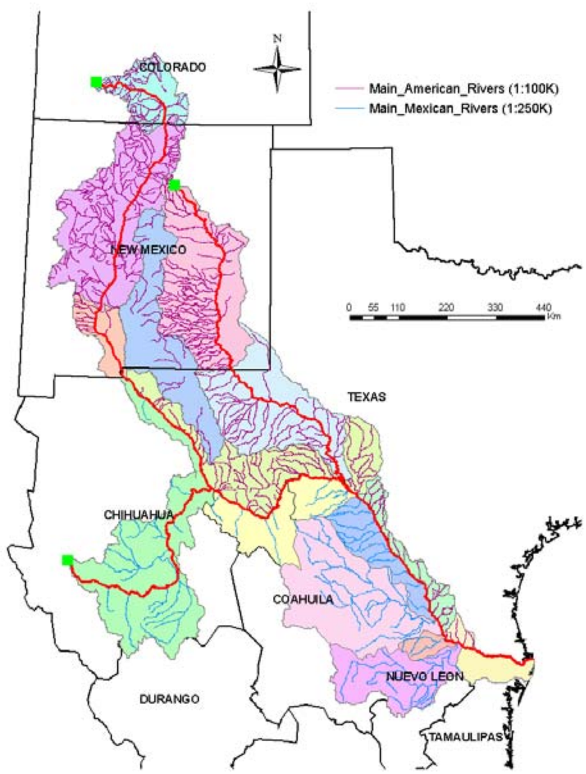

Figure 19 River segments in the Rio Grande/Bravo basin

5.2 Monitoring Point

Water quality stations, wastewater treatment plants, the NADBank projects location and other important control points are being included into the WQDB as a feature class called Monitoring Points.

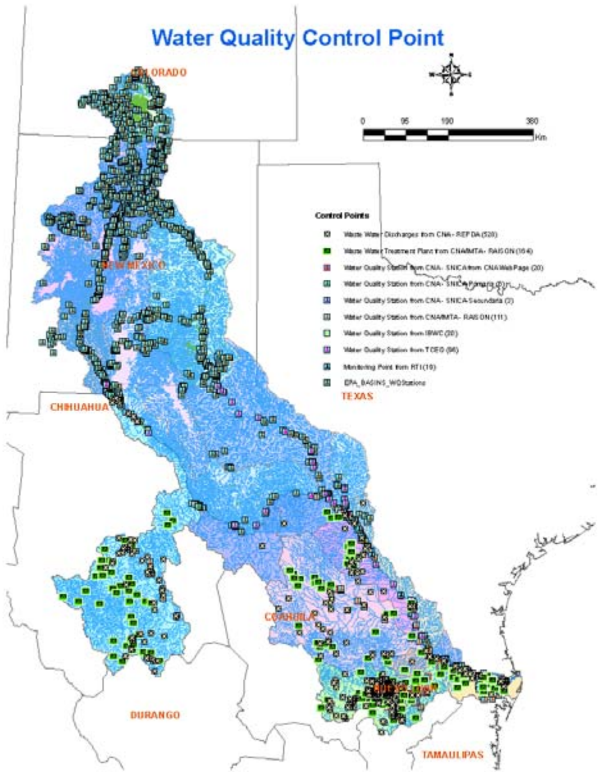

Figure 20 Water quality control points in the Rio Grande/Bravo basin.

5.3 Digital Orthophoto Quadrangles (DOQ)

An orthoimage is remotely-sensed image data in which displacement of features in the image caused by terrain relief and sensor orientation have been mathematically removed. Orthoimagery combines the image characteristics of a photograph with the geometric qualities of a map. The Landsat Mosaic orthoimagery database contains Landsat Thematic Mapper imagery for the conterminous United States. The more than 700 Landsat scenes have been resampled to a 1-arc-second (approximately 30-meter) sample interval in a geographic coordinate system using the North American Horizontal Datum of 1983. Three bands have been selected from the eight spectral bands available for each frame. These are bands 4 (near-infrared), 3 (red), and 2 (green), typically displayed as red, green, and blue, respectively. The image is a full-resolution (spectral and spatial), 24-bit color-infrared composite that simulates color infrared film as a "false color composite".

Purpose:

These data have been created as a result of the need for having geospatial data immediately available and easily accessible in order to provide geographic reference for Federal, State, and local emergency responders, as well as for homeland security efforts. Orthoimages also serve a variety of purposes, from interim maps to field references for earth science investigations and analysis. The digital orthoimage is useful as a layer of a geographic information system. This data can be used to provide reference information for Web browsers and for map applications at a scale of 1:100,000 or smaller. Larger scale orthoimagery such as digital orthophoto quadrangles will be more accurate, but often at the expense of timely updates.

The digital orthophoto was created for every hydrological subregion of the Rio Grande/Bravo basin, as it is shown in figure 21. This is the first time than an orthoimage is created specifically for the whole basin.

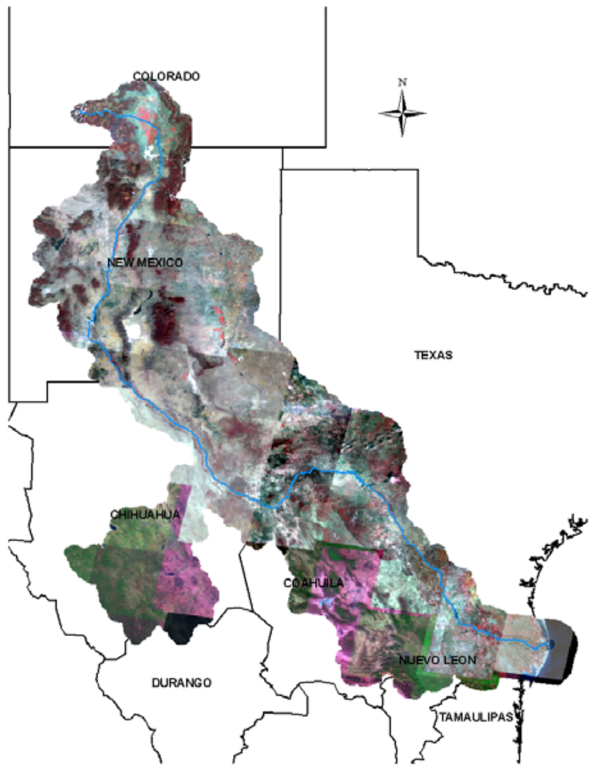

Figure 21 OrthoImage of the Rio Grande/Bravo basin

6 Conclusions

A binational geodatabase was created for the Rio Grande/Bravo basin that includes a relational database containing water quality, hydrologic, hydraulic, and related data. This geodatabase is being made available to Mexican and U.S. federal, state, and local organizations. It is a tool that can assist in promoting bi-national cooperation between Mexico and the United States concerning water in the Rio Grande basin, providing accurate and reliable data necessary for analysis and resolution of water resources issues. The first part of this project was to collect the water quality information from both Mexican and American agencies. This information did not have the same characteristics and accuracy in both sides, so it had to be edited, reprojected, and fixed in order to get unified criteria for the geodatabase.

One of the most important contributions of this research is the application of a Raster-Network Regionalization technique, which utilizes raster-based analysis at the subregional scale and network-based attribute accumulation at the regional scale in order to process large regions in an efficient manner. For large watersheds such as the Rio Grande/Bravo basin, the raster data is too large to be handled as one entity; this problem is dealt with by subdividing the basins into parts. The results from each sub-basin are merged on the vector side for determining parameters. This methodology helped to verify the validity of dividing a basin for processing without compromising on the accuracy of the parameter values determined. This technique could also be applied at a local level when high resolution data, such as LIDAR data, area available. These data are so dense they typically preclude raster analysis over a relatively small area.

A powerful conclusion from this project is that regional HydroID assignment is critical to the success of regionalization. The HydroID enables the connection between features in the landscape, including the connection of watersheds to outlet junctions, as well as the connection of junctions with next downstream junction. Also, it allows the integration of subregions into regions, through the update of the NextDownID in the most downstream junction in each region.

7 Acknowledgements

This research project was funded by the North American Development Bank and the Mexican National Water.

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